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Vaddiparty et al.

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(54) **RETURN LINK CHANNEL LOADING OF MULTIPLE SATELLITES WITH MULTIPLE SPREAD SPECTRUM USER TERMINALS**

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(22) Filed: **Oct. 13, 2000**

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(52) **U.S. Cl.** **455/12.1**; 455/450; 455/452; 455/427; 455/464

(58) **Field of Search** 455/12.1, 13.1, 455/427, 450, 509, 452, 464, 403, 422, 453, 7, 512

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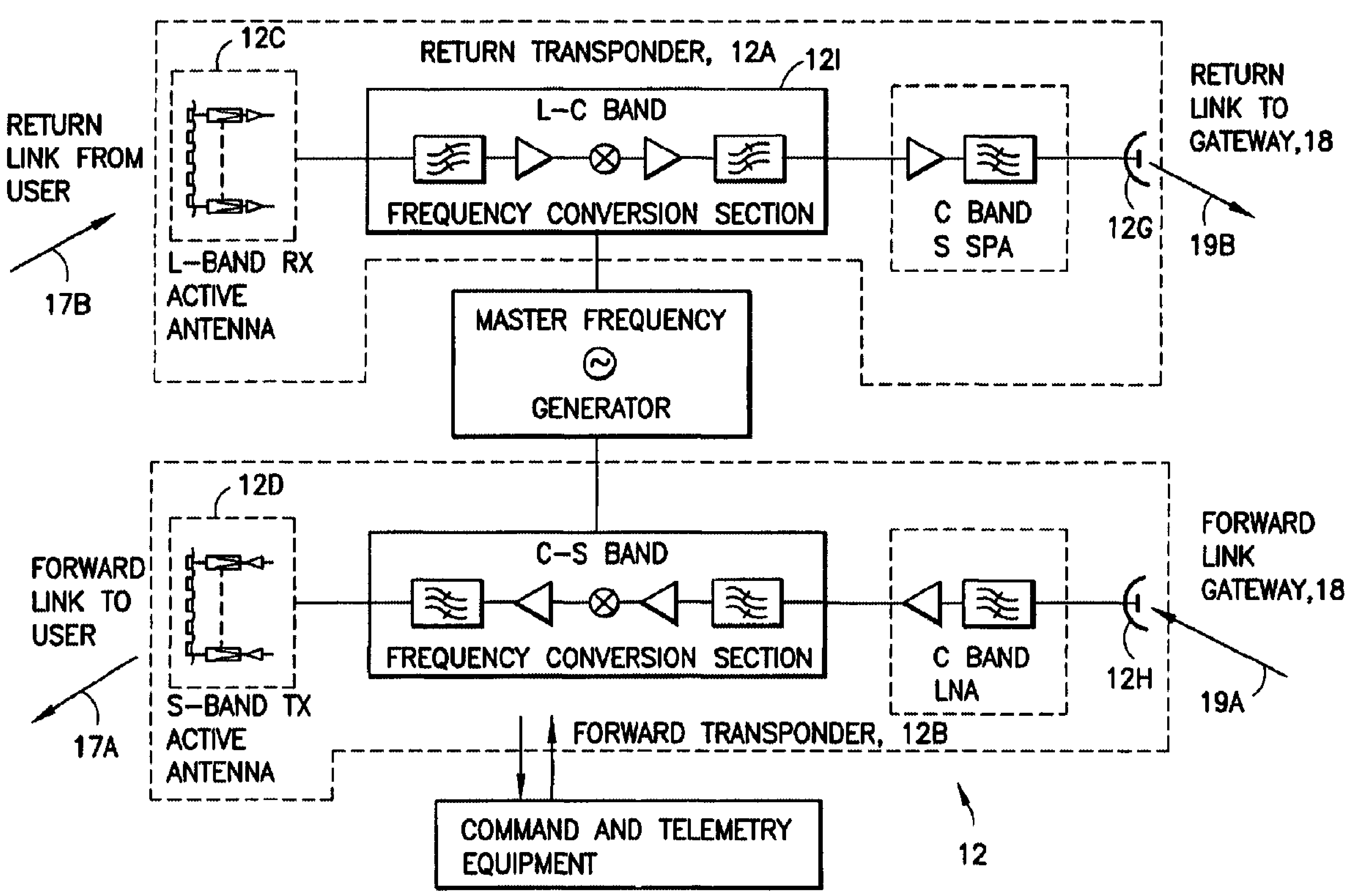
(57) **ABSTRACT**

The satellite communication system comprises a plurality of satellites. The frequency bandwidth of the return link to each satellite is subdivided into a plurality of channels. The method includes steps of finding a total interference in each channel, calculating a predicted total interference from addition of a first user terminal to each channel, determining if the predicted total interference is a minimum, and allocating the first channel to the first user terminal. The predicted total interference is calculated for each channel of the plurality of channels in the return link to each of at least two satellites. The first channel is allocated to the first user terminal if the predicted total interference in the first channel is the minimum value.

11 Claims, 9 Drawing Sheets



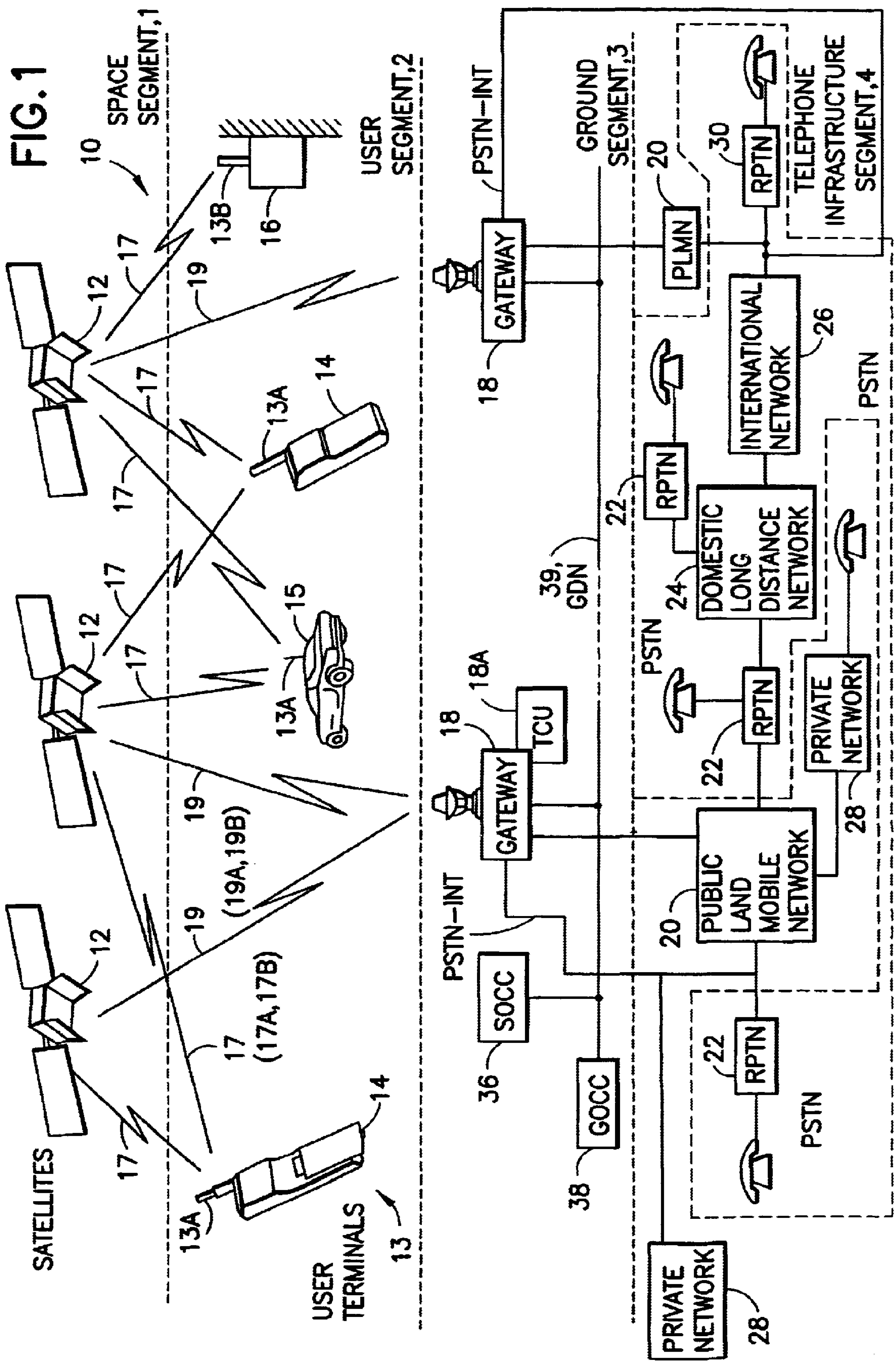


FIG. 1
10
SPACE SEGMENT, 1
SATELLITES
12
17
19
(17A,17B)
(19A,19B)
USER SEGMENT, 2
USER TERMINALS
13
13A
13B
14
15
16
GROUND SEGMENT, 3
GATEWAY
18
18A
TCU
PSTN-INT
SOCC
36
GOCC
38
39, GDN
TELEPHONE INFRASTRUCTURE SEGMENT, 4
PLMN
20
PUBLIC LAND MOBILE NETWORK
RPTN
22
DOMESTIC LONG DISTANCE NETWORK
24
INTERNATIONAL NETWORK
26
PRIVATE NETWORK
28
30
PSTN

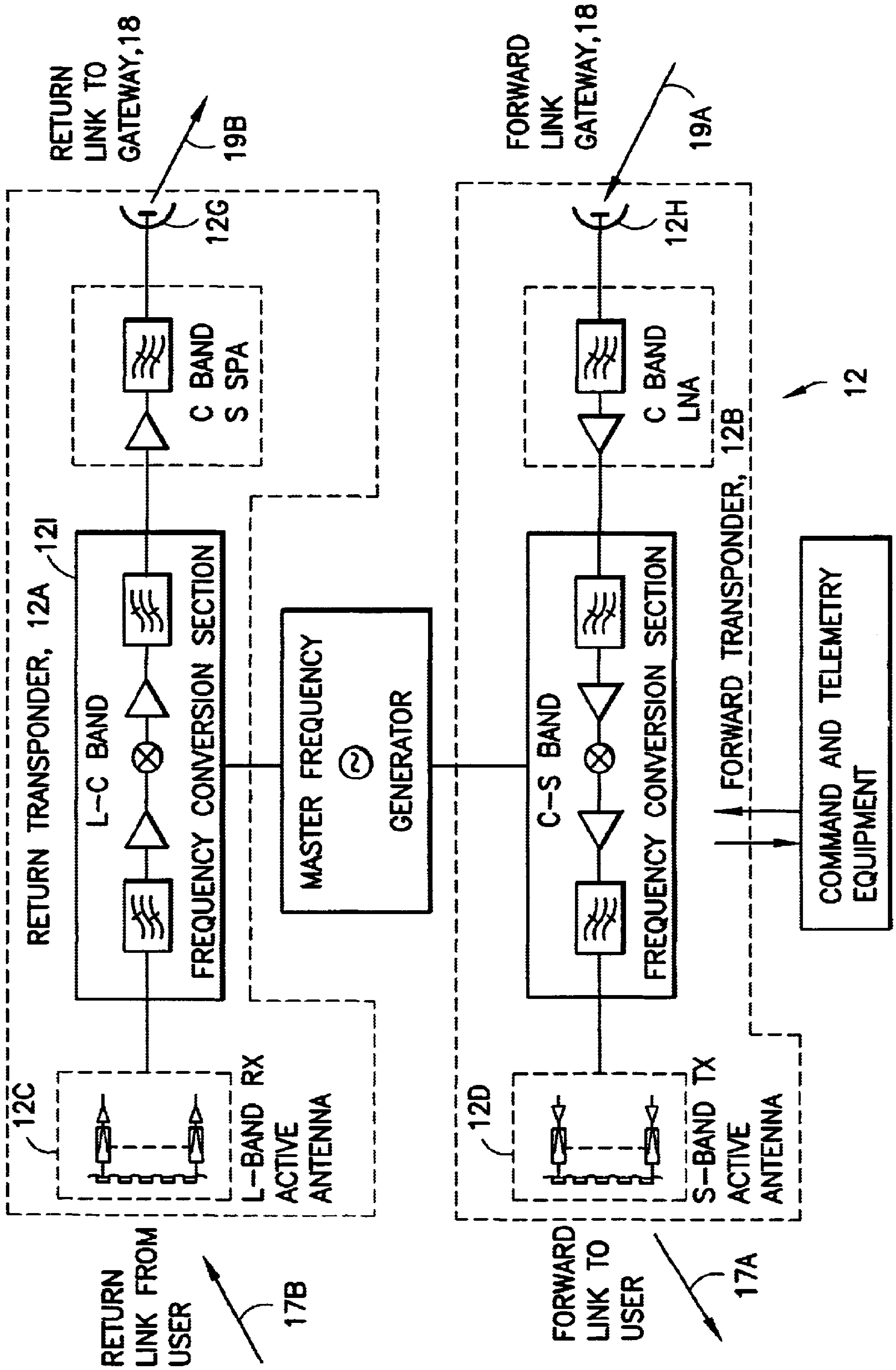

RETURN LINK TO GATEWAY,18
19B
12G
C BAND
S SPA
RETURN TRANSPONDER, 12A
12I
L–C BAND
FREQUENCY CONVERSION SECTION
MASTER FREQUENCY
GENERATOR
12C
L–BAND RX
ACTIVE
ANTENNA
RETURN LINK FROM USER
17B
FORWARD LINK GATEWAY,18
19A
12H
C BAND
LNA
12B
12
FORWARD TRANSPONDER, 12B
C–S BAND
FREQUENCY CONVERSION SECTION
COMMAND AND TELEMETRY EQUIPMENT
12D
S–BAND TX
ACTIVE
ANTENNA
FORWARD LINK TO USER
17A

FIG.2

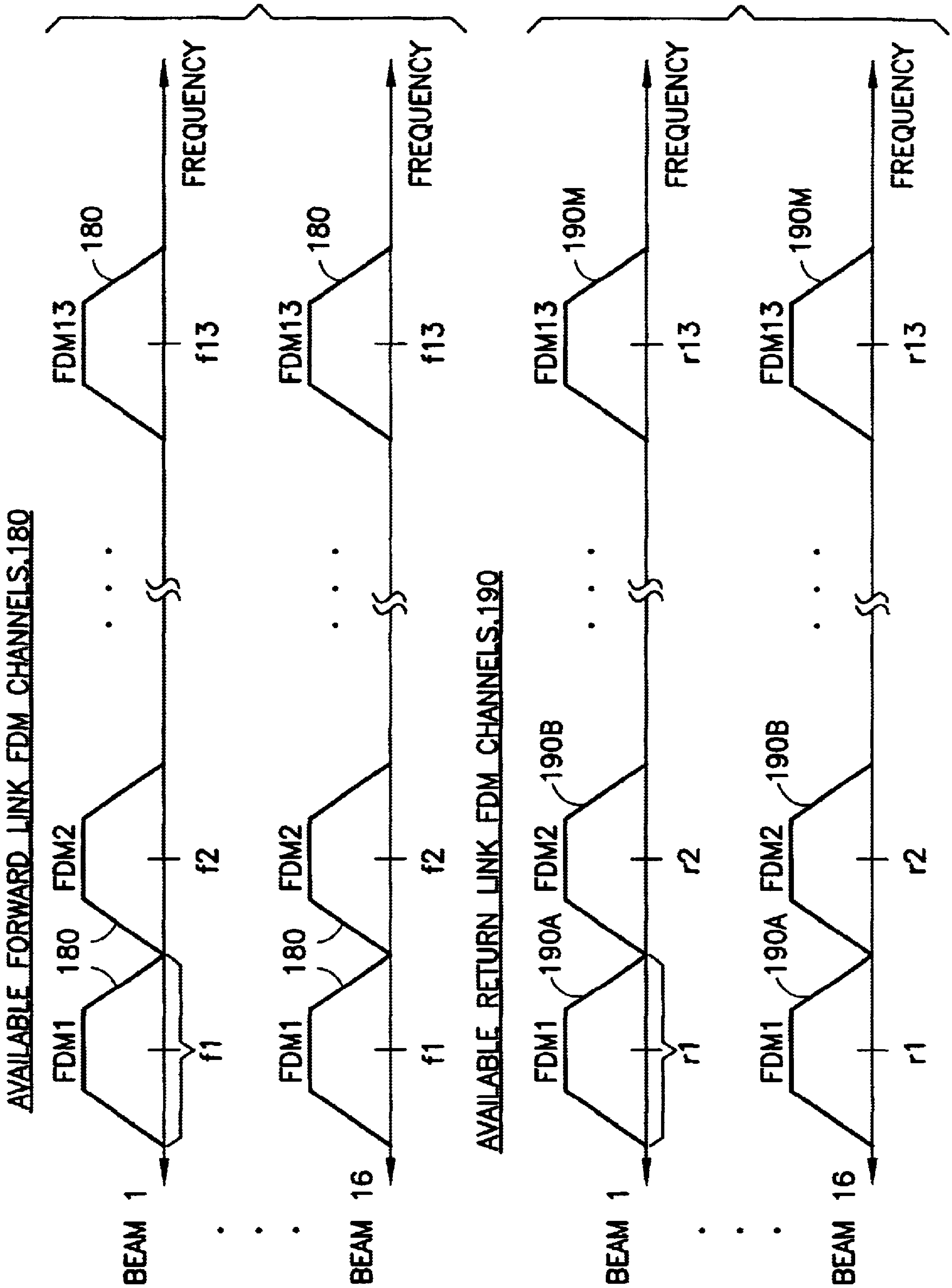

AVAILABLE FORWARD LINK FDM CHANNELS,180
BEAM 1
BEAM 16
FDM1
FDM2
FDM13
180
f1
f2
f13
FREQUENCY
AVAILABLE RETURN LINK FDM CHANNELS,190
190A
190B
190M
r1
r2
r13

FIG.3A

FIG.3B

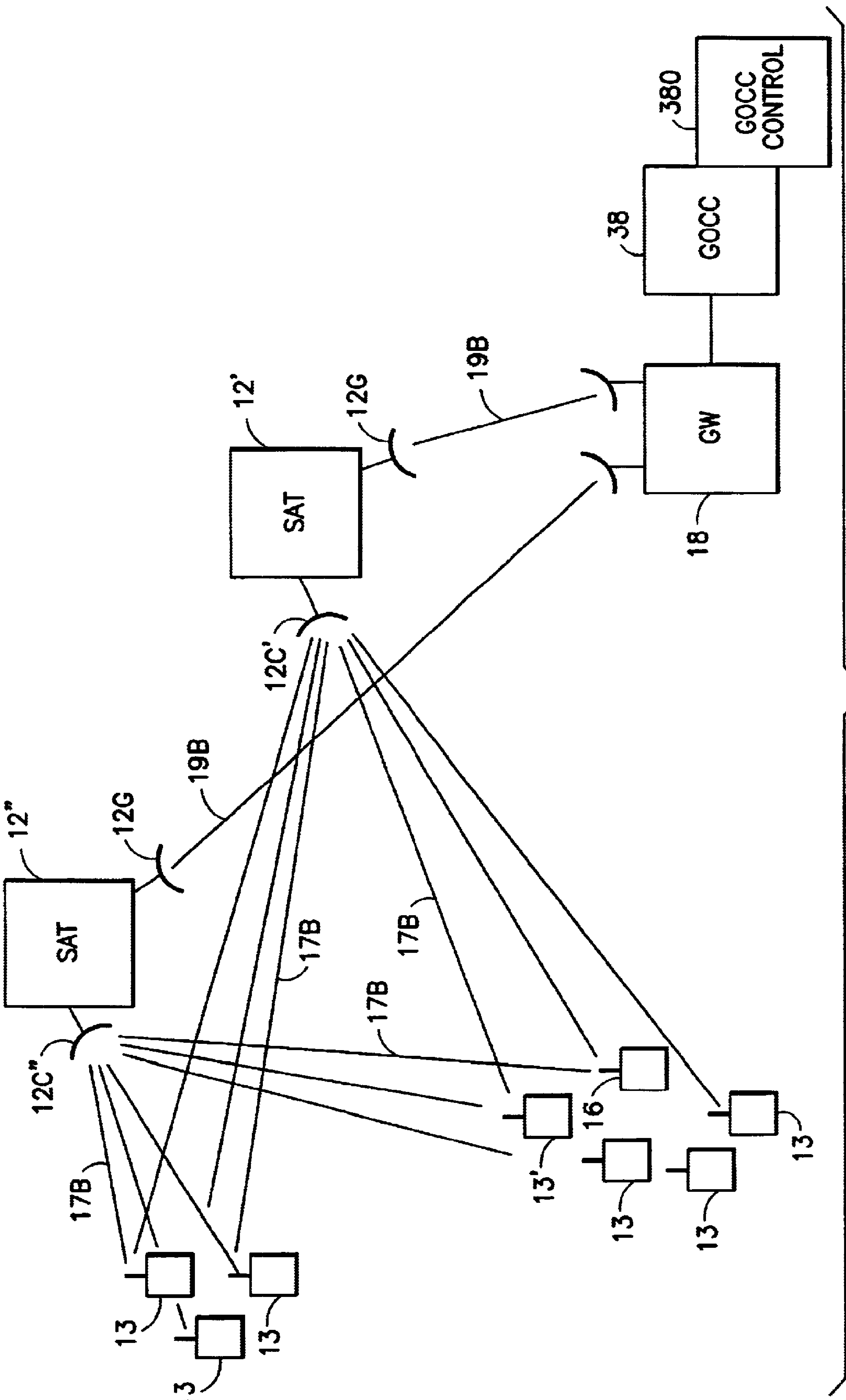

GOCC CONTROL
380
GOCC
38
GW
18
19B
12G
12'
SAT
12C'
19B
12G
12"
SAT
12C"
17B
17B
17B
17B
16
13'
13
13
13
13
13
13
13

FIG.4

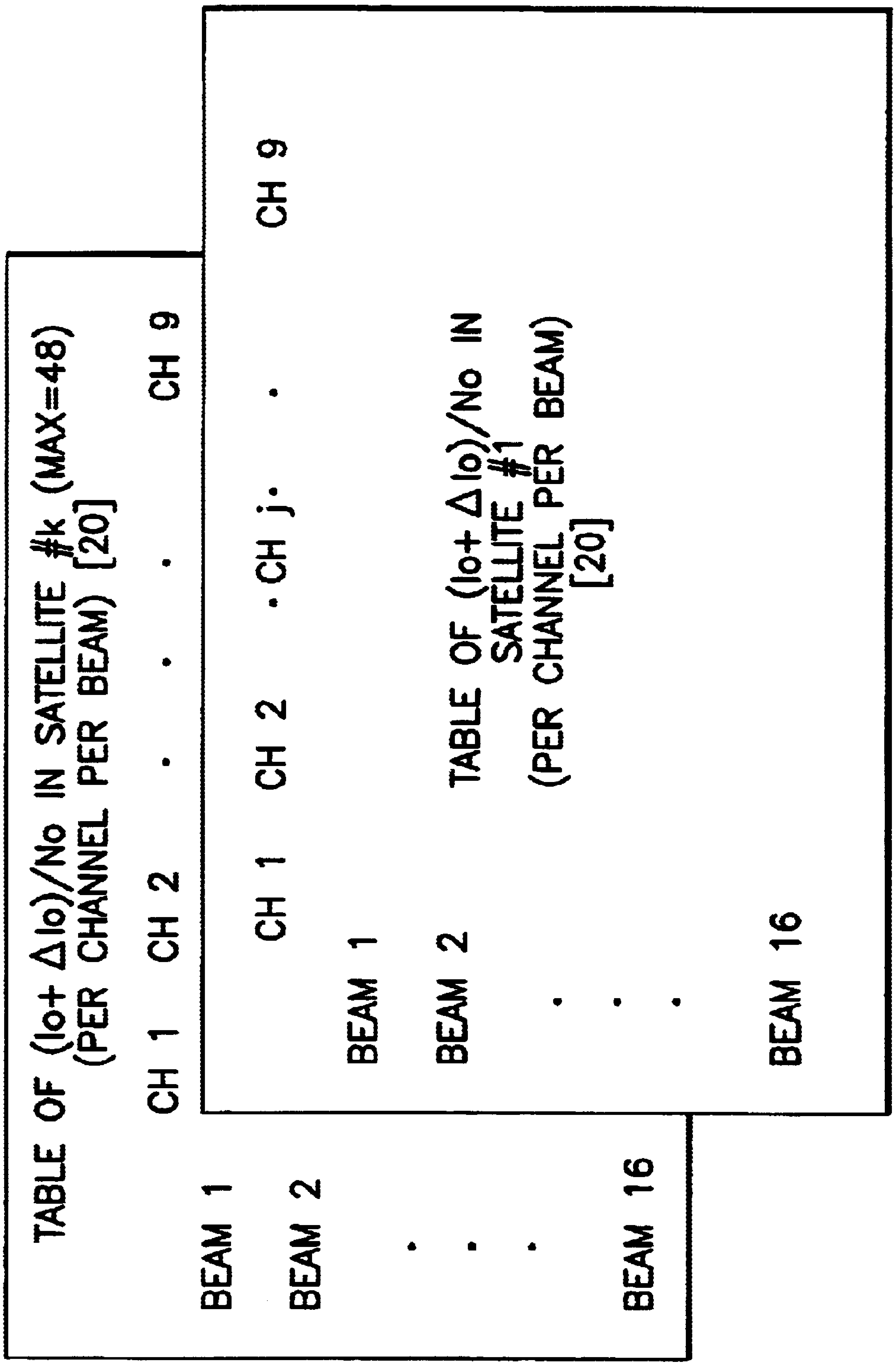


TABLE OF (Io+ ΔIo)/No IN SATELLITE #k (MAX=48)
(PER CHANNEL PER BEAM) [20]
CH 1
CH 2
CH 9
BEAM 1
BEAM 2
BEAM 16
CH 1
CH 2
CH j
CH 9
TABLE OF (Io+ ΔIo)/No IN SATELLITE #1
(PER CHANNEL PER BEAM)
[20]
BEAM 1
BEAM 2
BEAM 16

FIG.5

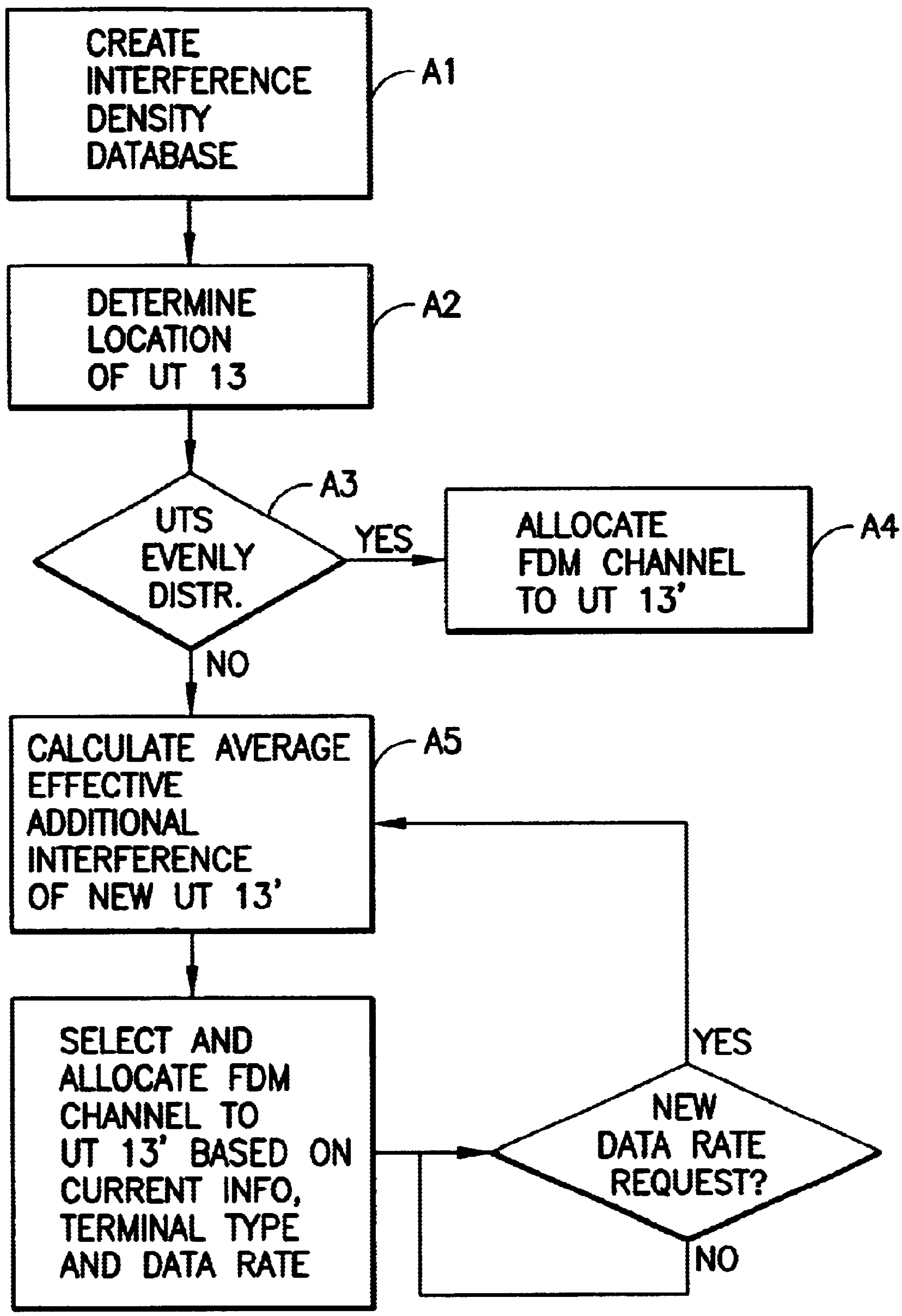

CREATE INTERFERENCE DENSITY DATABASE
A1
DETERMINE LOCATION OF UT 13
A2
UTS EVENLY DISTR.
A3
YES
ALLOCATE FDM CHANNEL TO UT 13'
A4
NO
CALCULATE AVERAGE EFFECTIVE ADDITIONAL INTERFERENCE OF NEW UT 13'
A5
SELECT AND ALLOCATE FDM CHANNEL TO UT 13' BASED ON CURRENT INFO, TERMINAL TYPE AND DATA RATE
NEW DATA RATE REQUEST?
YES
NO

FIG.6

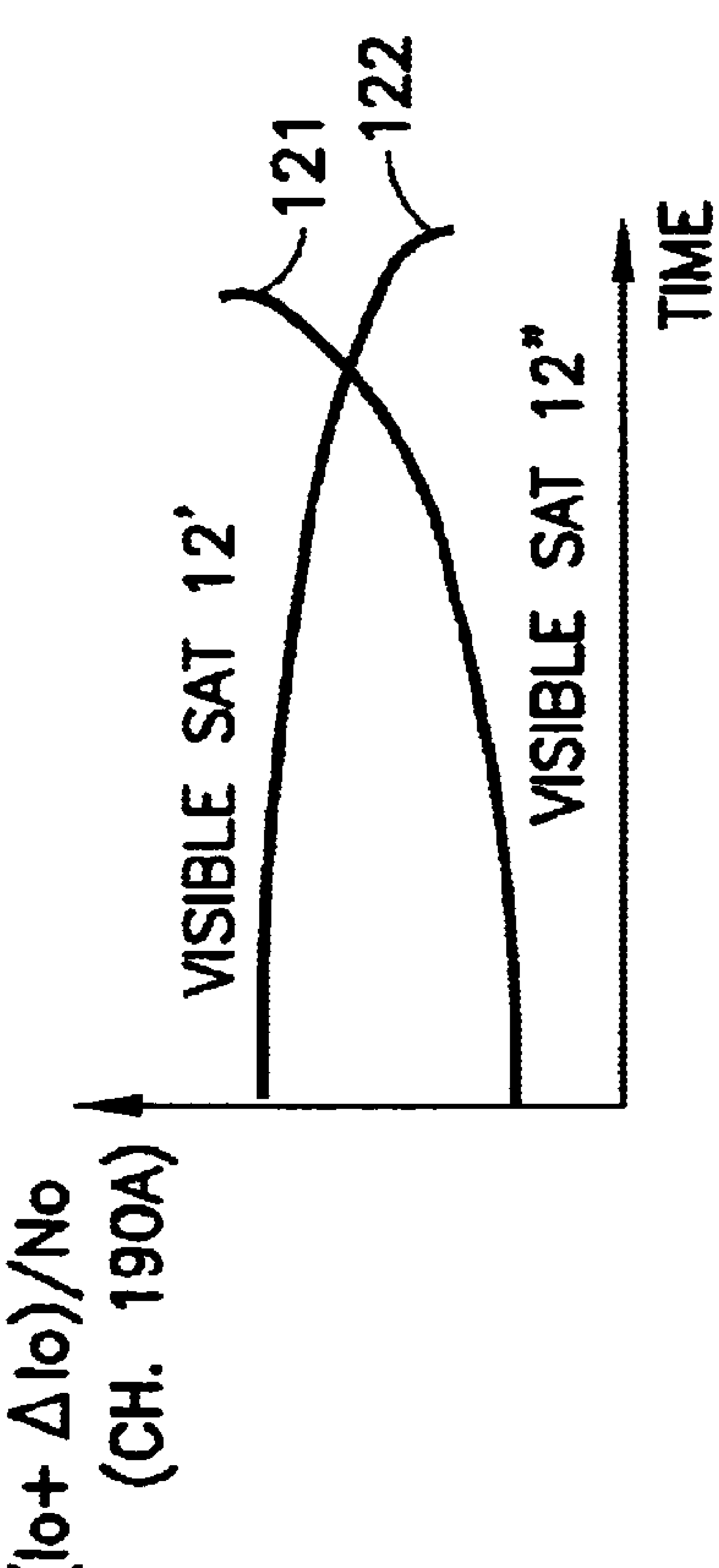


FIG.7A

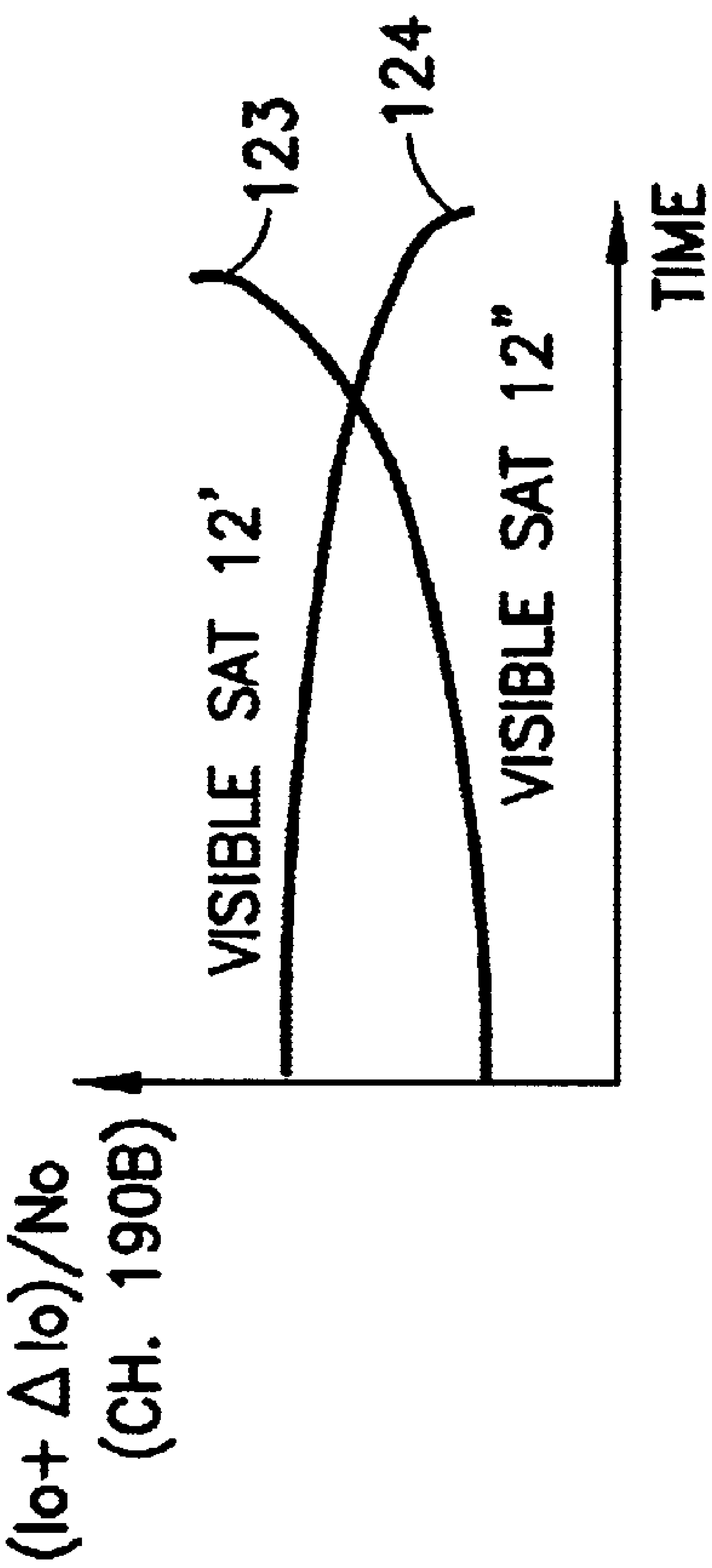


FIG.7B

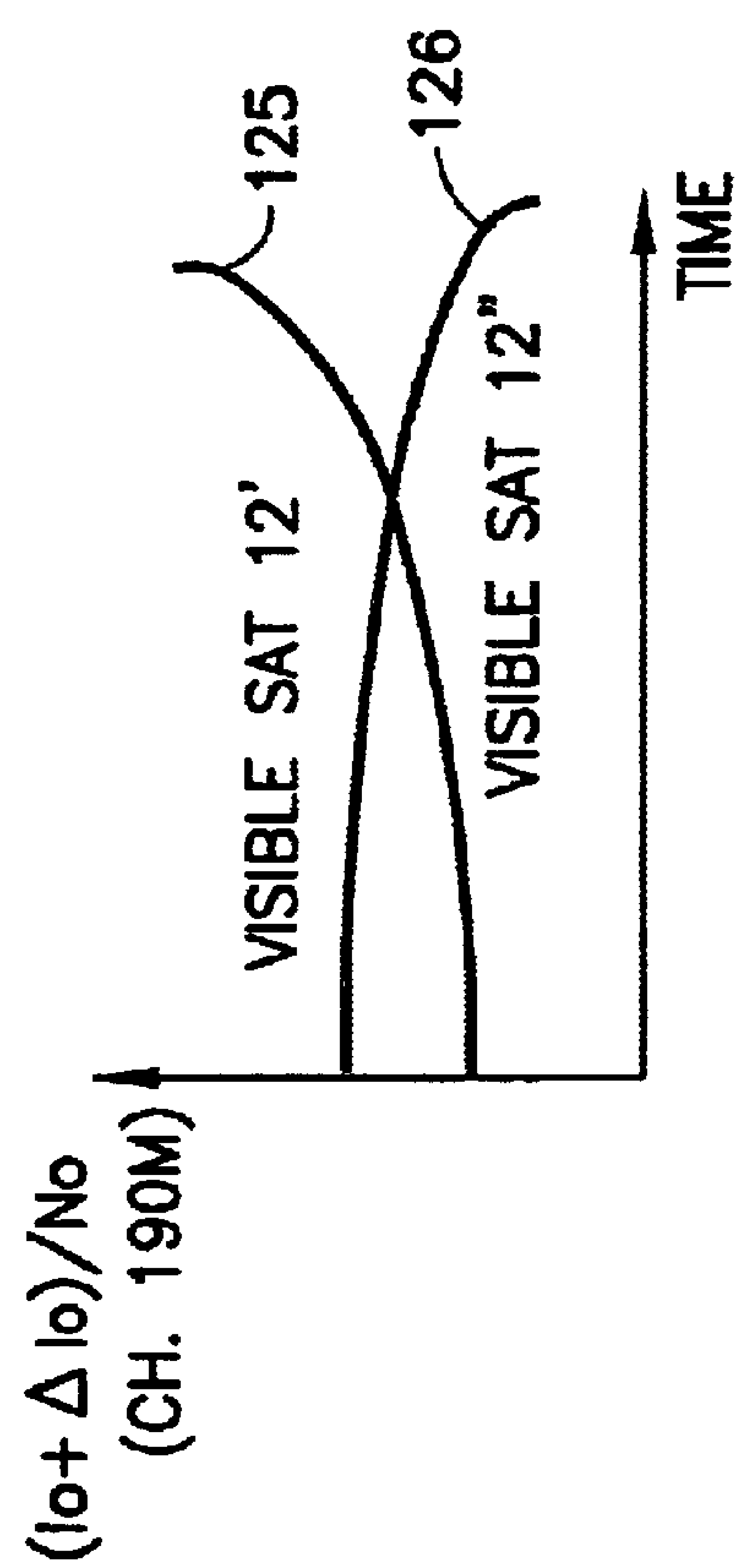


FIG.7C

INTERFERENCE TO THERMAL NOISE DENSITY MATRIX (μ) [27] IN THE EXAMPLE CASE OF 13 AVAILABLE FDM CHANNELS AND TWO VISIBLE SATELLITES [2]

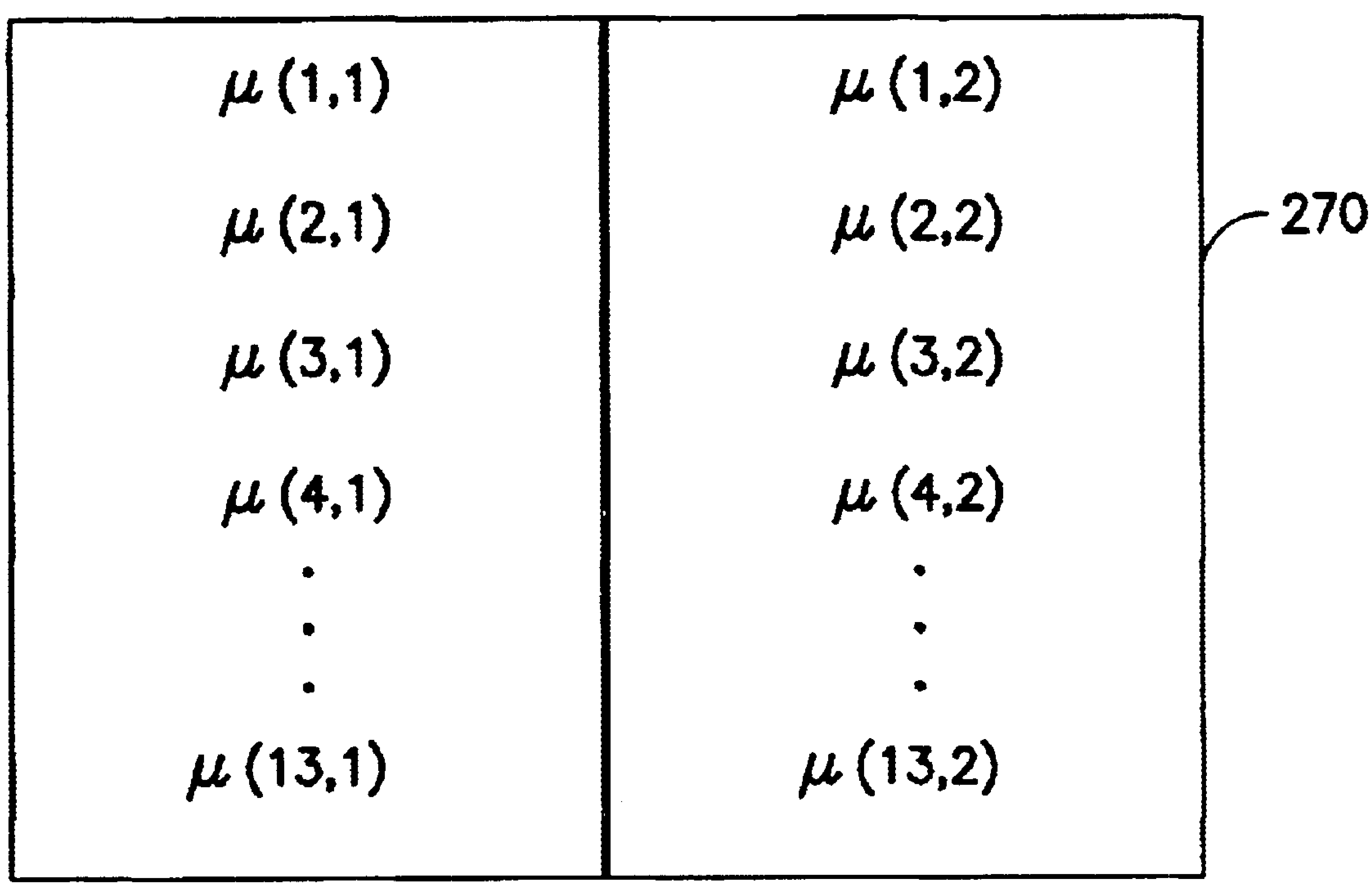


FIG.8

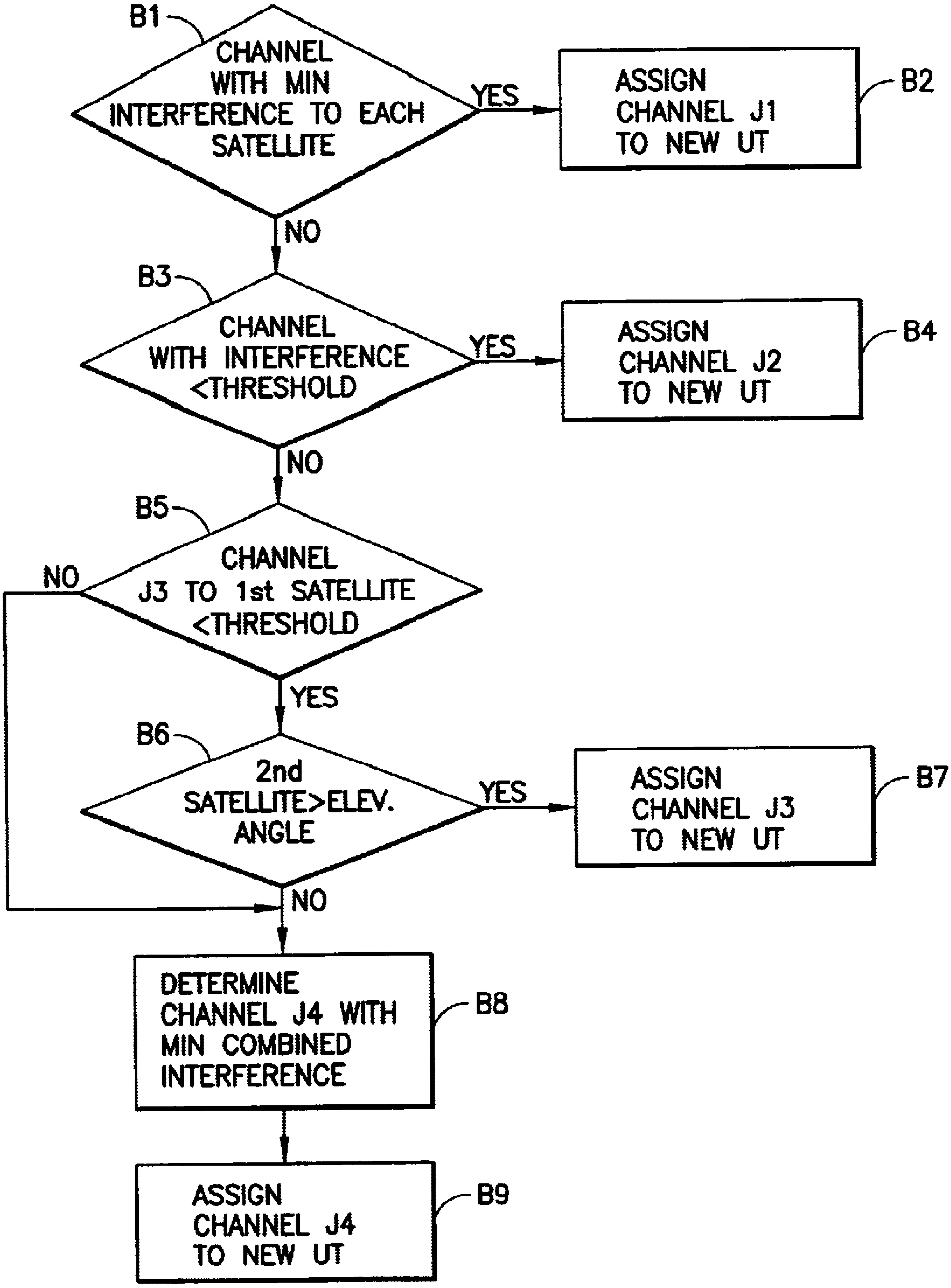

B1
CHANNEL WITH MIN INTERFERENCE TO EACH SATELLITE
YES
ASSIGN CHANNEL J1 TO NEW UT
B2
NO
B3
CHANNEL WITH INTERFERENCE <THRESHOLD
YES
ASSIGN CHANNEL J2 TO NEW UT
B4
NO
B5
CHANNEL J3 TO 1st SATELLITE <THRESHOLD
NO
YES
B6
2nd SATELLITE>ELEV. ANGLE
YES
ASSIGN CHANNEL J3 TO NEW UT
B7
NO
DETERMINE CHANNEL J4 WITH MIN COMBINED INTERFERENCE
B8
ASSIGN CHANNEL J4 TO NEW UT
B9

FIG.9

RETURN LINK CHANNEL LOADING OF MULTIPLE SATELLITES WITH MULTIPLE SPREAD SPECTRUM USER TERMINALS

FIELD OF THE INVENTION

This invention relates in general to satellite-based communication systems, and specifically, to satellite-based mobile telecommunication systems.

BACKGROUND OF THE INVENTION

Satellite communication systems are well known in the prior art. Examples of such systems are disclosed in U.S. Pat. No. 5,303,286 and other publications that are of record in said patent. In satellite communication systems, user terminals and gateways generally communicate with each other via one or more co-visible satellites (i.e. satellites "seen" by both the user terminals and the gateways). Some of the user terminals have broad beam antennas which illuminate much of the sky. The broad beam illumination contributes to interference with other user terminals using the covisible satellites. Furthermore, user terminals and gateways of the satellite communication system may communicate using a spread spectrum (SS) code division multiple access (CDMA) technique. The nature of communication using SS CDMA method is that the signal from a single user terminal is spread across the entire bandwidth of a given communication channel. Therefore, all user terminals communicating on a given communication channel may contribute to interference with another user terminal communicating on that channel. An increase in the number of user terminals on a given communication channel tends to increase overall interference, as does an increase in any individual user terminal's transmit power when it is desired to boost the signal over the overall interference level of the channel.

OBJECTS AND ADVANTAGES OF THE INVENTION

It is a first object and advantage of this invention to provide a system and method to minimize total interference within a given channel of a satellite communication system.

It is a second object and advantage of this invention to provide a satellite communication system having the ability to assign communication channels to user terminals to achieve optimal performance of the satellite communication system.

SUMMARY OF THE INVENTION

The foregoing and other problems are overcome and the objects of the invention are realized by methods and apparatus in accordance with embodiments of this invention, wherein in accordance with a first method of the present invention, a method for maximizing capacity of a satellite communication system is provided. The method comprises the steps of finding a total interference in each frequency channel, calculating a predicted total interference from the addition of a first user terminal on each frequency channel, determining if the predicted total interference in a first channel is a minimum value, and allocating the first channel to the first user terminal. The total interference is found for each channel of a plurality of channels which subdivide a predetermined frequency band of a return link for at least two satellites. The predicted total interference from the addition of the first user terminal is calculated in each

channel of the plurality of channels in the return link for each of the least two satellites. A determination of whether the predicted total interference is a minimum value in the first channel is made with respect to all predicted total interference values for the plurality of channels in the return link. The first channel is allocated to the first user terminal if the predicted total interference of the first channel is the minimum value.

In accordance with a second aspect of the present invention, a method is disclosed for assigning a frequency channel to a user terminal of a satellite communications system. The user terminal is assumed to be visible to at least two satellites. The method comprises the steps of identifying a location of the user terminal, determining if a first frequency channel of a plurality of frequency channels has a minimum total interference and, if yes, assigning the first frequency channel to the user terminal. If not, a next step determines if a second frequency channel has a total interference below a predetermined threshold and, if yes, assigns the second frequency channel to the user terminal. If this test fails, the method then determines if a third frequency channel has a total interference below the predetermined threshold for a first one of the two satellites, and a total interference above the predetermined threshold for a second one of the two satellites. If yes, the method determines if the first satellite is at a lower elevation angle than the second satellite, relative to the user terminal, and if yes, the method assigns the third channel to the user terminal, otherwise a fourth frequency channel is assigned for the return link of the user terminal. The location of the user terminal may be identified when the user terminal requests service. Determination of whether the first frequency channel has a minimum total interference is made for the return link of the user terminal to each one of the two satellites. The determination if the second frequency channel has a total interference below the predetermined threshold is also made for the return link of the user terminal to each satellite.

BRIEF DESCRIPTION OF THE DRAWINGS

The above set forth and other features of the invention are made more apparent in the ensuing Detailed Description of the Invention when read in conjunction with the attached Drawings, wherein:

FIG. **1** is a block diagram of a satellite communication system that is constructed and operated in accordance with a presently preferred embodiment of this invention;

FIG. **2** is a block diagram of the communications payload of one of the satellites of the satellite communication system of FIG. **1**;

FIGS. **3**A and **3**B respectively, are graphical representations of a forward radio-frequency (RF) link spectrum and a return RF link spectrum used by the communication system of FIG. **1**, showing the frequency division multiplexing (FDM) of forward and return link beams;

FIG. **4** is a simplified block diagram showing a portion of the communication system shown in FIG. **1**;

FIG. **5** is a three dimensional matrix graphically depicting a database of interference values per satellite per return link FDM channel per beam of the communication system of FIG. **1**;

FIG. **6** is a flow chart graphically depicting the method for allocating FDM channels to return link users of the communication system of FIG. **1**;

FIGS. **7**A–**7**C are three graphs respectively depicting the total interference density with respect to time on three different FDM channels of two satellites of the system of FIG. **1**, when a new user terminal return link is added to the subject channels of the two satellites;

FIG. **8** is a two dimensional matrix graphically depicting the average interference density in each FDM channel per satellite available for use by a new user terminal to communicate with a gateway of the system shown in FIG. **1**; and

FIG. **9** is a flow chart graphically depicting a subsequence of the method depicted in FIG. **6** for allocating FDM channels to return link users of the communication system of FIG. **1**.

DETAILED DESCRIPTION OF THE INVENTION

FIG. **1** illustrates a presently preferred embodiment of a satellite communication system **10**, such as for example the Globalstar™ system, which is suitable for use with the presently preferred embodiment of this invention. Although the present invention will be described with reference to the embodiment shown in the drawings, it should be understood that the present invention can be embodied in many alternate forms of embodiments.

The satellite communication system **10** shown in FIG. **1** generally comprises a space segment **1**, a user segment **2**, a ground segment **3** and a telephone system infrastructure segment **4**. Satellite communication systems are described in U.S. Pat. Nos. 5,619,525, 5,758,261, 5,634,190 and 5,640,386, which are incorporated by reference herein in their entirety. In the preferred embodiment, the space segment **1** comprises a network of satellites **12** in Low Earth Orbit (LEO). The constellation of LEO satellites **12** contains an appropriate number of satellites distributed in a suitable number of orbital planes such that the system **10** provides substantial full-earth coverage with preferably, at least two satellites **12** in view at any given time from a particular user location. The satellites **12** effect communication between user terminals **13** and gateways **18**. Thus, a user terminal **13** may communicate from substantially any point on Earth with any other point via one or more gateways **18** and one or more **10** satellites **12**, possibly also using a portion of the telephone infrastructure segment **4**. In the preferred embodiment, the satellites **12** function solely as "bent-pipe" repeaters. As such, the satellites **12** receive communication traffic signals (such as speech and/or data) from user terminals **13** or from gateways **18**, convert the signals to another frequency band and then re-transmit the converted signal. There is no on-board signal processing of a received communications traffic signal. In alternate embodiments, the satellites may be configured to perform some, or complete, on-board processing of received communications traffic signals.

The user segment **2** includes a plurality of user terminals **12**. Each user terminal **13** comprises a transmitting device capable of operating with the satellite system **10**. The user terminals **13** include generally a plurality of different types such as hand-held mobile radio-telephones **14**, fixed radio-telephones **16** or vehicle mounted radio-telephones **15**. The user terminals **13** contain the necessary baseband and RF electronics and antennas to both transmit and receive via satellites **12** voice and/or data with the appropriate signaling structure. The user terminals **13** are preferably provided with omni-directional antennas **13***a* for bi-directional communication via one or more of the satellites **12**. The vehicle mounted **15** and fixed **16** radio-telephones may also incorporate directional antennas **13***b*. The directional antennas on fixed radio-telephones **16** may be pointed (steered). Otherwise, the fixed radio-telephones may incorporate multiple antenna elements which may be switched (commutated).

The user terminals **13** may be capable of operating in a full duplex mode and communicate via, by example, L-band RF links (uplink or return link **17***b*) and S-band RF links (downlink or forward link **17***a*) through return and forward satellite transponders **12***a* and **12***b* respectively. The return L band RF links **17***b* may operate within a frequency range of 1.61 GHz to 1.625 GHz, a bandwidth of 16.5 MHz. The return links **17***b* are modulated with packetized digital voice and/or data signals using a spread spectrum (SS) technique. In the preferred embodiment, the spread spectrum communications technique employs Direct Sequence (DS) spreading in conjunction with Code Division Multiple Access (CDMA). The forward S band RF links **17***a* may operate within a frequency range of 2.485 GHz to 2.5 GHz, with a bandwidth of 16.5 MHz. The forward links **17***a* are also modulated at a gateway **18** with packetized digital voice and/or data signals using the DS-CDMA technique.

The ground segment **3** includes at least one, but generally a plurality of the gateways **18** that communicate with the satellites **12** via, by example, a full duplex C band RF link **19** (forward link **19***a* (to the satellite) and return link **19***b* (from the satellite)) that operates within a range of frequencies preferably in the C-band. The C-band RF links **19** bi-directionally convey the communication feeder links, and also convey satellite commands to the satellites and telemetry information from the satellites **12**. The forward feeder link **19***a* may operate in the band of 5 GHz to 5.25 GHz, and the return feeder link **19***b* may operate in the band of 6.875 GHz to 7.075 GHz. The satellite **12** has feeder link antennas **12***g* and **12***h* through which duplex communication between the satellite **12** and gateway **18** are conducted. The gateway **18** receives the return link **19***b* energy transmitted by all satellites **12** within its field-of-view, and contains all of the necessary RF, down conversion/demodulation and based band electronics to reproduce the voice/data generated at the user terminals in digital form. The gateway **18** interfaces the resulting digital stream to Public Switched Telephone Network (PSTN) infrastructure segment **4**. Once this voice/data has entered the PSTN infrastructure, the voice/data is directed to its desired destination, including back to another user terminal within the referenced satellite communication system, if desired. Conversely, voice/data entering the gateway **18** through the PSTN infrastructure is transmitted via the forward link **19***a* to the satellites **12** which amplify, down-convert from C- to S-band and re-transmit via forward link **17***a* to the user terminal **13**.

The ground segment **3** also comprises a Satellite Operations Control Center (SOCC) **36** and a Ground Operations Control Center (GOCC) **38**. A communications path **39** is provided for interconnecting the gateways **18**, SOCC **36** and GOCC **38**. This portion of the communications system **10** provides overall system control functions.

Also as shown in FIG. **1**, the PSTN infrastructure segment **4** generally comprises existing telephone systems. For example, the PSTN infrastructure includes Public Land Mobile Network (PLMN) gateways **20**, local telephone exchanges such as regional public telephone networks (RPTN) **22** or other local telephone service providers. The PSTN infrastructure may also include domestic long distance networks **24**, international networks **26**, private networks **28** and other RPTNs **30**.

Referring also to FIG. **2**, the satellites **12** have L-band **12***c* and S-band **12***d* antennas through which full-duplex mode communication is conducted between the satellites **12** and the user terminals **13**. The L-band and S-band antennas are multiple beam antennas that provide coverage within an associated terrestrial service region. For example, the L-band **12***c* and S-band **12***d* antennas illuminate the earth respectively with 16 beams for receiving from and 16 beams for transmitting to the user terminals **13**. Although the structure of these beams may or may not be different, the continuously orbiting constellation of satellites **12** provide coverage on most of the earth's surface 24 hours a day. As this is an integrated world-wide system, subscribers are given the flexibility to use their user terminals **13** anywhere in the world (roaming). Furthermore, in the preferred embodiment, the LEO constellation of satellites **12** may have more than one satellite in view of both (i.e. covisible) a given user terminal **13** and gateway **18**, so that multiple communication paths may be established between them. For example, in the satellite communication system **10**, each duplex communication between a given one of the user terminals **13** and a corresponding gateway **18** generally comprises a forward link **19***a*, **17***a* (gateway **18** to user terminal **13**) via two or more satellites **12** in the field of view of both the gateway and user terminal, and a return link **17***b*, **19***b* (user terminal **13** to gateway **18**) via the covisible satellites **12**. Thus, two or more satellites **12** may each convey the same communication between the given user terminal **13** and the gateway **18**. Furthermore, the return and forward links **17***b*, **17***a* between the user terminal **13** and satellites **12** may use one or more beams of the satellites' L-band and S-band antennas **12***c*, **12***d* illuminating the user terminal. The multiple transmission paths coincident with this mode of operation thus provides for diversity combining at the respective receivers, leading to an increased resistance to fading and facilitating the implementation of a soft handoff procedure. The effect of this diversity is exploited to enhance system performance.

The forward link RF spectrum (e.g. 16.5 MHz S-band) preferably contains thirteen different Frequency Division Multiplexed (FDM) channels centered at frequencies f_1 to f_{13}, which are contiguously spaced within the assigned frequency allocation.

It should be noted that the forward link RF spectrum may contain any number of channels and each channel could have a different bandwidth (e.g., 1.25 MHz, 3.75 MHz, etc.).

FIG. **3**A shows a graphical representation of the FDM channels **180** subdividing the beams of the forward downlink **17***a* (satellite **12** to user terminal **13**). The frequency structure of the forward uplink **19***a* from the gateway **18** to the satellites **12** (not shown) is substantially similar to that of the forward downlink **17***a*. The FDM channels **180** are, for example, 1.23 MHz wide in frequency. Each of these thirteen FDM channels contain multiple voice and/or data and some overhead functions such as a pilot, paging and synchronization signals. The thirteen FDM channels per forward link beam, and sixteen beam structure of the forward link antenna **12***d*, provides for a sixteen-fold frequency re-use for forward link transmissions. The preferred DS-CDMA communication technique which is used when transmitting these signals employs up to, for example, **128** different Walsh spreading codes within each FDM channel. This allows a variable number of users to simultaneously occupy the same FDM channel. The gateway **18** transmits the appropriate amount of power through the satellites **12**, and by means of link quality measurements at the user terminals **13**, the transmit power is dynamically adjusted to achieve optimal link-by-link performance.

The return link **17***b*, **19***b* frequency plan is graphically depicted in FIG. **3**B. The return link **17***b*, **19***b* RF spectrum has similar frequency structure to that of the forward downlink **17***a*, **19***a* with, for example, up to thirteen FDM channels **190** centered at frequencies r_1 to r_{13} which are contiguously spaced within the assigned return link **17***b*, **19***b* bandwidths. The return link **17***b*, **19***b*, which also incorporates the DS-CDMA technique, allows up to, by example, **128** users to transmit voice and/or data signals on each return link channel **190**. In addition, each return link channel supports signaling information from the user terminals **13** to the gateway **18** including access requests, power change request and registration requests. The return link **17***b*, **19***b* generally features active closed-loop power control (i.e. the user terminal's **13** transit power is dynamically altered to account for propagation effects based on received signal strength at the gateway **18**). The thirteen FDM channels **190** per return link beam and sixteen beams provide for a sixteen-fold frequency re-use for return link transmissions. The exact number of FDM channels available for the return link, however, may vary on a regional basis depending on the number of operating CDMA systems, regulatory issues, and inter-system coordination efforts. A given user terminal **13** may or may not be assigned a different return link channel **190** than the channel **180** assigned on the forward link. However, when operating in the diversity reception mode on the return link **17***b*, **19***b* (the gateway **18** receiving the user terminal's transmission from two or more satellites **12**), the user terminal **13** is assigned the same forward and return RF link channel **180**, **190** for each of the satellites **12**. For both links, the gateway **18**, under allocation strategies defined by the GOCC **38**, or defined by the gateway itself **18**, is responsible for assigning the specific FDM channel to a given user terminal **13**. The GOCC **38** is responsible for managing all the gateways **18**.

The return link **17***b*, **19***b* in the satellite communication system **10** may be different than its forward link **19***a*, **17***a*, in that the latter uses coherent detection whereas the former uses non-coherent detection. The user terminals **13** include multiple receivers to accept forward RF link **19***a*, **17***a* energy from up to three different paths using a three finger rake receiver (receivers including three distinct RF/IF/Demodulation paths). In the return link **17***b*, **19***b*, the gateway **18** may have up to a seven finger rake receiver, thereby non-coherently combining return RF link energy through up to seven different paths. As noted previously, these paths may convey energy between a single gateway **18** through several satellites **12** and/or several beams through one satellite **12**.

The near omni-directional antennas of hand-held user terminals **14** and vehicle mounted user terminals **15** illuminate the sky almost uniformly. This broad beam illumination in the return uplink **17***b* impinges on the covisible satellites **12** and contributes to interference on the return link FDM channels **190**. The level of interference on the return link FDM channels directly determines the capacity of the return link FDM channels. Generally, CDMA modulation techniques spread the signal from an individual user terminal **13** across the entire bandwidth of a given FDM channel. Therefore, all users within the FDM channel may represent interference to the signal of interest, unless the other signals are otherwise orthogonal (in code space) to the signal of interest. In the forward link **19***a*, **17***a*, all signals within an FDM channel **180** are assigned orthogonal Walsh codes by the gateway **18**. In the return link **17***b*, **19***b* the overall interference, and hence the capacity of one FDM channel **190**, is generally dependent on the signal-to-noise-ratio (SNR), or its equivalent in the digital domain, energy-per-bit to noise-density

$$\left(\frac{E_b/N_o}{1+I_o/N_o}\right)1$$

ratio. The terms E_b, N_o, and I_o respectively represent; the received power per data rate (i.e. energy per bit), the thermal noise density and the total interference noise density (in 1 Hz of the FDM channel bandwidth). The interference density (I_o) is a function of the number of user terminals **13** using the FDM channel (i.e. system capacity) and their corresponding transmitted RF power. The term (I_o/N_o) represents the additional degradation in a given FDM channel of a given satellite **12** from the ideal no interference (I_o=0) case and provides a convenient metric in evaluating the return link performance.

As the number of users in an FDM channel increases, by example, to increase system capacity, then the overall interference increases. In order to achieve the appropriate energy per bit to noise density rate

$$\left(\frac{E_b/N_o}{1+I_o/N_o}\right)2$$

on the FDM channel, it may be desirable to increase the transmitted power from the user terminal **13**. The higher transmit power from the user terminal in turn further increases the interference to other UTs on the same FDM channel.

The gateway **18**, either directly or otherwise under control of the GOCC **38**, allocates the resources of the satellite communication system **10** (i.e. satellites **12** and FDM channels **180**, **190**) to the forward **19***a*, **17***a* and return links **17***b*, **19***b* to achieve optimal operation of the system. Examples of systems and methods for allocating satellite communication system resources to forward link users are described in U.S. Pat. Nos. 5,592,481 and 5,812,538 incorporated by reference herein in their entirety. In the present invention, the gateways **18**, either directly, or under control of the GOCC **38**, assign the return link users to specific FDM channels **190** such that the total interference is minimized within the assigned FDM channel and performance of the system is optimized.

Referring now to FIG. **4**, there is shown a simplified block diagram of a portion of the satellite communication system **10**. The present invention will be described with specific reference to this portion of the satellite communication system **10** shown in FIG. **4**, though the present invention applies equally to the whole system. In FIG. **4**, a number of user terminals **13**, **13'** are shown transmitting signals to one gateway **18** through two satellites **12'**, **12"** visible to both the user terminals and the gateway. Due to orbital geometry, each of the two satellites **12'**, **12"** is at a different elevation relative to a given user terminal **13**, **13'**. The user terminals **13**, **13'** are distributed on the earth's surface so that each user terminal is illuminated by one or more beams of the L-band antenna **12***c*', **12***c*" on each of the two satellites **12'**, **12"**. A return uplink **17***b* is established between each user terminal **13** and each satellite **12'**, **12"**. Each satellite receives the signals from each transmitting user terminal **13** via the return uplink. Each satellite then repeats the return link signals and transmits them to the gateway **18**. Generally, the user terminals **13** are not uniformly distributed, but rather, tend to cluster in geographic regions on the earth's surface. This clustering may lead to some beams illuminating the earth from the satellite L-band (return link) antenna **12***c*', **12***c*" being heavily utilized while others remain fallow. The resulting system capacity is thus not maximized, which in turn raises the transmit power demands on the user terminals (i.e. the system performance is non-optimal).

The effects of clustering by user terminals on system performance are mitigated in the present invention by selectively assigning return link channels to the user terminals.

In the preferred embodiment, the GOCC **38** has a master controller **380** which allocates a return link FDM channel to each user terminal in accordance with the method described below. In alternate embodiments, one or more of the gateways may have a controller to allocate the return link FDM channel to the user terminals. Preferably, the master controller **380** is aware of the type and location of each of the user terminals **13** in communication or initiating communication with the gateway. For example, the gateway **18** may have a capability of detecting and tracking the location of each user terminal with which the gateway is communicating. This may be accomplished by an appropriate locating algorithm programmed into the gateway which uses the signals relayed by multiple satellites to locate the user terminal on the earth's surface. Otherwise, the user terminal may include a position determining device, the location data from which may be transmitted by the user terminal on one of the return link overhead channels. The user terminal type (i.e. vehicle mounted or hand-held) may be included in the information signals transmitted by the user terminal **13** to the gateway **18** during registration (and from the gateway **18** to the master controller **380**). Preferably, the master controller **380** may also be aware of the position, at any given time, of all the satellites **12** in the constellation of satellites of the communication system **10** as well as the number of FDM channels available in the region of the earth illuminated by each satellite's return link antenna **12***c*', **12***c*". Satellite position data may be established from telemetry data transmitted by the satellites to the gateway. The master controller **380** may otherwise be programmed with additional system architecture parameters as well as other ancillary information to facilitate selection of the FDM channels as will be described in further detail below. In an alternate embodiment, the gateway **18** may be aware of the position of all the satellites **12** in the constellation of satellites of the communication system **10** at any given time. The gateway may also be aware of the number of FDM channels available in the region of the earth illuminated by each satellite's return link antenna **12***c*', **12***c*". In addition, the gateway **18** may further be programmed with additional system architecture parameters as well as other ancillary information to facilitate selection of the FDM channels as will be described in further detail below.

Referring now to FIG. **6**, there is shown a flow chart which graphically illustrates the method for allocating FDM channels to return link users. An overview of the method is substantially as follows. First, in step **A1** of FIG. **6**, a database of the interference density to thermal noise ratio (I_o/N_o) for every return link FDM channel **190** into each satellite **12** is initially created at some initial time t_o. After this database is created, in step **A2** the location and type of a given user terminal **13'** is determined when the user terminal **13'** makes a request for service to the gateway **18**. The request for service may include a requested data rate. During a session the data rate request can be made which increases or decreases the current data rate. This may occur multiple times during a connection.

With the location and type of the new user terminal **13'** (i.e. the user terminal requesting service) identified, then in step **A3** a determination is made as to the geographical distribution of other user terminals **13** communicating with the gateway **18** via the same satellites **12** as the new user terminal **13'**. If it is determined that the user terminals **13, 13'** are substantially evenly distributed, then in step **A4** of FIG. **6**, an FDM channel is allocated to the new user terminal **13'** such that all the FDM channels have a substantially uniform user distribution. However, if it is determined that the user terminals **13, 13'** are not uniformly distributed geographically, then in Step **A5**, the average effective additional interference ($\Delta I_o/N_o$) from the new user terminal **13'** is calculated for each return link FDM channel into the satellites used by the new user terminal **13'**. From the additional interference, the appropriate FDM channel is selected and allocated in Step **A6** to minimize the total interference on the FDM channels of the satellites **12** as will be described in greater detail below. After FDM allocation in step **A6**, the user terminal **13'** may request an increase or decrease in the current data rate as mentioned above, and as shown in step **A7** of FIG. **6**. In the event the user terminal **13'** makes such a request, the average effective additional interference ($\Delta I_o/N_o$) from the user terminal **13'** is again calculated in step **A5** for each return link FDM channel into the satellites used by the user terminal **13'**. From the additional interference, an appropriate FDM channel is again selected and allocated in Step **A6** to minimize the total interference on the FDM channels of the satellites **12**. As mentioned above, the user terminal **13'** may make a data rate change request multiple times during a connection.

For each new terminal requesting service, steps **A2–A6** of the above described procedure are repeated as necessary.

The database created in Step **A1** of FIG. **6**, is generated, using an appropriate processor in the master controller **380** of the GOCC **38**. In an alternate embodiment, the database created in Step **A1** of FIG. **6** may be generated by a controller in the gateway **18**. The database includes values for the ratio of interference density to thermal noise density (I_o/N_o) for each FDM channel **190** within each return link beam of each satellite **12** in the constellation of satellites of the communication system **10**. A schematic representation of this database **200** of (I_o/N_o) values is shown in FIG. **5** as a three dimensional matrix with the beams and FDM channels arranged respectively in rows and columns arrayed by satellite. This database **200** generally represents the net interference status on all the FDM channels **190** of the return links **17*b*** into each of the satellites **12** of the satellite constellation of the communication system **10** (see also FIG. **1**). The data base is created at some initial time or epoch (t_0=0) during operation of the satellite communication system **10**. This initial time may coincide with the start of service of the communication system **10**. The thermal noise density N_o is a predetermined value which is a function of the satellite's **12** communication payload and is otherwise registered in the master controller processor of the GOCC **38** or a controller in the gateway **18**. The thermal density N_o may be identified, for example, a priori from ground testing of each satellite's communication payload. The interference density I_o on each FDM channel of each beam may be referenced, by example, at the return uplink Low-Noise-Amplifier (LNA) (not shown) which is part of the L-band antenna **12*d*** of each satellite **12**. Otherwise, the interference density I_o may be referenced anywhere within each satellite's **12** communication electronics chain. The data base **200** of (I_o/N_o) values is periodically updated. Each of the interference density to thermal noise (I_o/N_o) values in the data base **200** is dynamically adjusted over time relative to the initial epoch (t_0=0). The adjustments to the (I_o/N_o) values may be performed at some pre-defined time increments by either the gateway **18** or the GOCC **38**. For example, adjustments to the values in the data base **200** could be made every minute either in near real time at the gateway **18** and/or in a predictable mode at the GOCC **38**. Initially, the (I_o/N_o) values in the data base **200** may be established by either following the methods described below from the start of service, or otherwise derived analytically based on a priori knowledge of the locations of the user terminals **13** and satellites **12** at a given time, based on suitable return link analyses techniques.

Referring now to FIGS. **3B**, **4** and **6**, the location of a given user terminal **13'** is determined in Step **A2** of FIG. **6**, whenever a request for service is made by the user terminal to the gateway **18**. The request for service may be made in response to a need to establish a communication link between the user terminal **13'** and gateway **18**, or may be generated so as to handoff an already established link from one satellite to another. Generally, the request for service is made by the user terminal **13'** at some time t after the initial epoch t_0. The location of the user terminal **13'** requesting service is used in conjunction with information otherwise stored in the master controller processor or the gateway **18** to determine, at time t, which satellites **12'**, **12"** are visible to that user terminal **13'**, the corresponding beams of the satellites illuminating the user terminal **13'** as well as the number of FDM channels **190** otherwise available to the user terminal **13'**. In addition to the location of the user terminal, the type of user terminal **13'** requesting service (i.e. hand-held or vehicle mounted radio-telephone) is also established in step **A2** of FIG. **6**. From the type of user terminal, the master controller **380** of the GOCC **38**, or the gateway **18**, may then determine the link closure requirements (e.g. energy-per-bit to noise-density ratio, antenna characteristics) which are different for different types of user terminals. The link closure requirements can be used to either mix or segregate user terminals **13** within an FDM channel.

If in Step **A2** it is determined that all user terminals **13, 13'** visible to the given satellites **12'**, **12"** are substantially uniformly located on the ground, then the return link FDM channel **190** is allocated to the new user terminal **13'** in step **A4** to distribute the transmitting user terminals substantially uniformly on all FDM channels **190**. In this case, the uniform assignment approach may be appropriate to minimize the total interference density to thermal noise ratio (I_o/N_o) within any FDM channel into the satellites **12'**, **12"**. If the traffic through the gateway **18** serving the given geographic region does not warrant the full complement of available FDM channels the number of available FDM channels may be reduced accordingly in that region. Reducing the number of available FDM channels reduces the cost of the gateway **18** due to reduced hardware, software and maintenance requirements.

If the user terminals **1** are determined, however, not to be uniformly distributed on the ground, the next step (i.e. step **A5** of FIG. **6**) is to calculate the average (over time) effective additive interference ratio ($\Delta I_o/N_o$) the new user terminal **13'** will add if it is assigned to any one of the available return link FDM channels **190**. The normalization factor (thermal density N_o) is arrived at as previously described. The additive interference density (ΔI_o) of the new user terminal **13'** is calculated for all return link FDM channels **190** (in this case there are thirteen FDM channels though this number may vary) of all covisible satellites **12'**, **12"** (in this case there are two covisible satellites though this number may also vary) through which the return link **17*b***, **19*b*** to the gateway **18** may be established. The additive interference density is preferably calculated by the master controller **380** of the GOCC **38**. The additive interference (ΔI_o) is generally defined by the ratio (P_r/r_i) where P_r represents the power of the new user terminal's **13'** transmission received at each covisible satellite L-band antenna **12***d* and r_i is the bandwidth (e.g. 1.23 MHz) for each FDM channel (i=1–13 in this case). The transmission received power P_r is in turn generally related to the transmit power P_t of the user terminal **13'** requesting service. The transmit power P_t demanded of the user terminal **13'** so that it may be assigned to any of the available FDM channels **190** may be determined using conventional return link closure analyses techniques.

For example, the power P_t of the user terminal **13'** to transmit on any FDM channel **190** is generally a function of factors such as: a) the range between transmitter and receiver and corresponding space loss; b) the gain and losses of the user terminal's antenna **13***a* and satellite's L-band antenna **12***c*', **12***c*" (in particular the gain of the L-band antenna beam where the new user terminal **13'** is currently located); c) L-band antenna **12***c*', **12***c*" beam efficiency; d) the average data rate of the user terminal **13'**; e) voice activity effects; f) the overall interference on the FDM channels **190**; g) the transmit power of stations transmitting to other RF services in the geographical location of the new user terminal **13'** and h) the expected duration of transmission of the new user terminal **13'**. The master controller **380** of the GOCC **38** is suitably programmed to quantify the above listed factors from ephemeral data received from the user terminals **13**, the satellites **12** and gateways **18**, or otherwise from data registered in the master controller processor.

It should be noted that in an alternate embodiment the gateway **18** may calculate the additive interference density and further may be suitably programmed to quantify the above listed factors from ephemeral data received from the user terminals **13**, the satellites **12**, or otherwise from data registered in the gateway **18** itself.

In this case, for example, the range (factor (a)) between the transmitter and receiver is calculated from the location of the user terminal **13'**, identified in Step **A2**, and that of each relaying satellite **12'**, **12"** registered previously in the gateway **18** and/or the master controller **380**. The L-band antenna beam efficiency (factor (c)), (i.e. the roll-off characteristics of neighboring beams from which unintended energy is impinging into the FDM channel within the beam illuminating the new user terminal **13'**) is otherwise established through prior testing of the L-band antenna **12***c*', **12***c*" and then registered in the master controller **380**. The average transmission data rate (factor (d)) and the voice activity effects (factor (e)) of the terminal are quantified from predictive models (which state what an average user terminal may transmit for different percentages of time at different data rates and identify a margin on the average data rate to account for instantaneous data rates different than the average value). The overall interference (factor (f)) on the FDM channels (an indication of the number of user terminals **13** already active within each of the FDM channels) is identified from the database matrix **200** (see FIG. **5**) created in Step **A1** and updated as described further below. The expected duration of transmission (factor (h)) is a value also generated preferably by the master controller **380** of the GOCC **38** based on accepted predictive methods which attempt to account for the time period that the new user terminal **13'** will be transmitting at the average data rate (in this case a period of two minutes may be selected though, other time periods may be chosen as desired). Alternatively, the expected duration of transmission (factor (h)) may be generated by the gateway **18**.

The transmit power of stations for other RF services (factor (g)) operating proximate to the location of the new user terminal **13'**, such that they may potentially interfere with the terminal's transmissions, is generally predicted by the master controller **380** of the GOCC **38** using one or more of the following methods. For example, the master controller **380** may be programmed with information identifying potentially interfering RF services (e.g. those RF services expected to be using radio frequencies proximate the L-band bandwidth used by the return link **17***b* of the communication system **10**) around the world. From this pool, the master controller **380** identifies those services sufficiently proximate geographically to the location of the new user terminal **13'**, identified in Step **A2**, to cause interference. The master controller **380** of the GOCC **38** then establishes the number of transmitting stations and characteristics associated with these services. Otherwise, the master controller **380** may use a predictive factor for these systems that includes some assumptions with respect to the number and characteristics of the RF services potentially interfering with the user terminal **13** transmissions. (e.g. A reasonable assumption may be that the number and characteristics of other system's stations are equal to those of the satellite communication system **10**. A scaling factor may also be applied based on the assumption that the other system's transmit power may be scaled as the square of the ratio of the altitude (or average of the slant ranges) of the other system's satellites to the altitude (or average of the slant ranges) of the satellites **12** of the communication system **10**.)

It should be noted that, in an alternate embodiment, the transmit power of stations for other RF services (factor (g)) may be predicted by the gateway **18**.

The master controller **380** of the GOCC **38** employs the above listed factors in the return link closure analysis to find the transmit power demand P_t on the new user terminal **13'** so that it may transmit on any FDM channel **190** of each relaying satellite **12'**, **12"**. The received power P_r at the LNA of the satellite's L-band antenna **12***c*', **12***c*" is then calculated, also for each FDM channel, based on the user terminal's transmit power P_t adjusted by the path gain (i.e. space loss and antenna characteristics; previously identified factors (a) and (b)). Finally, the additive interference (ΔI_o) value into each FDM channel **190** at each satellite **12'**, **12"** may then be determined from the ratio (P_r/r_i) of the received power at the LNA of the satellite's L-band antenna **12***c*', **12***c*" to the FDM channel bandwidth. The additive interference (ΔI_o) represents the increase in interference into each of the available FDM channels **190** within each of the covisible satellites **12** from addition of the new user terminal **13'**. The additive interference is normalized by the thermal density value N_o to find the additive interference density ($\Delta I_o/N_o$). By evaluating ($\Delta I_o/N_o$) at each satellite's L-band antenna **12***d* and using this parameter as the metric of comparison across all the FDM channels **190**, the effect of different path losses (i.e. space loss and antenna characteristics) and user terminal transmit power P_t are substantially accounted for.

The return link closure analysis, as described above, will yield a series of values of the additive interference density ($\Delta I_o/N_o$) which may be plotted with respect to time per FDM channel **190** to account for effects arising from movement of the relay satellites **12'**, **12"** with respect to the new user terminal **13'**. The effects of the satellite's movement (i.e. orbital rotation) relative to the new user terminal **13'** on the interference density of the FDM channels **190** is shown in FIGS. **7A–7C**. FIGS. **7A–7C** are three graphs of the total interference density $(I_o+\Delta I_o)/N_o$ plotted over time for three representative return link FDM channels (i.e. the first **190A**, the second **190**B and the thirteenth **190**M FDM channels, see also FIG. **3**B). Each graph shows a set of curves (**121**, **122** in FIG. **7**A; **123**, **124** in FIG. **7**B and **125**, **126** in FIG. **7**C), each curve in the set corresponding to the particular FDM channel received into one of the relay satellites **12**', **12**". In this case, there are two relay satellites **12**', **12**" and hence two curves per set. The total interference density $(I_o+\Delta I_o)/N_o$ represents the cumulative interference into each FDM channel **190** from the user terminals **13** already active, at time t, within each of channel (this base interference density (I_o/N_o) value is given by database **200**) and the additive interference density $(\Delta I_o/N_o)$ of the new user terminal if added to each channel. Each curve in the graphs of FIGS. **7**A–**7**C shows the change to the total interference density $(I_o+\Delta I_o)/N_o$ per channel per satellite due to relative motion of the satellite with respect to the new user terminal **13**' over the expected duration of the call (for example, two minutes). Here, the graphs of FIGS. **7**A–**7**C portray the case where one satellite **12**" is retreating and the other satellite **12**' is approaching the new user terminal **13**' along their orbital paths. Thus, referring to FIG. **7**A, if the user terminal **13**' were assigned to the first FDM channel **190**A (also see FIG. **3**B), the total interference to thermal noise density in the first channel **190**A of satellite **12**" may be mapped as curve **122**, and in the first channel **190**A of satellite **12**' as curve **121**. Curve **122** is decreasing (i.e. decreasing interference) over the call duration because satellite **12**' is moving closer to the user terminal **13**' (presenting a higher elevation angle relative to the user terminal). Curve **121** is increasing (i.e. increasing interference) because satellite **12**' is moving farther away (presenting a lower elevation angle relative to the user terminal). The interference curves in FIG. **7**B (curves **123**, **124**) and in FIG. **7**C (curves **125**, **126**) are similar in curvature (i.e. rate of change) to those in FIG. **7**A, though the magnitudes may be different. Similar sets of curves would be generated by the master controller **380** of the GOCC **38** for each return link FDM channel **190** (in this case, thirteen sets of curves would be generated, one for each of the thirteen FDM channels). The master controller **380** of the GOCC **38** then averages (with respect to time) each of these curves leading to, in this case, twenty six averaged predicted total interference values (one for each of the thirteen return link channels per satellite times two visible satellites). The result is a predicted average total interference on each return link channel **190** into each relay satellite **12**", **12**' from transmission by the new user terminal **13**'. The rate of change (i.e. curvature) of the interference curves **121**"**126** in FIGS. **7**A–**7**C is shown only for example purposes and may be different in actuality. For example, if the satellite communication system **10** of the preferred embodiment has active power control, as it exists in a satellite communication system such as the Globalstar™ system, the rate of change in the curves may be significantly lower (and will actually be flat in the case of ideal power control). In addition, the set of curves for each channel need not have one curve with a positive (increasing) rate of change and the other with a negative (decreasing) rate of change. Both curves may have negative a rate of change, as in the case where both satellites are approaching the user terminal **13**'. Alternatively, in the case where both satellites are retreating from the user terminal, both curves may have a positive rate of change.

While the return link closure analysis is described above as being performed by the master controller **380** of the GOCC **38**, it should be noted that, in an alternate embodiment, that the return link closure analysis may be performed by the gateway **18**.

For notational simplicity, the average expected total interference density per return link channel per satellite will be referred to hereafter as $\mu(j,k)$ where: $\mu=(I_o+\Delta I_o)/N_o$; j corresponds to a specific return link FDM channel (e.g. j=1 for the first FDM channel **190**A, j=2 for the second FDM channel **190**B and so on to j=13 for the thirteenth FDM channel **190**M of the return link) and k corresponds to a specific satellite (e.g. k=1 for satellite **12**", k=2 for satellite **12**'). Therefore, the parameter $\{\mu\}$ may be defined as a two dimensional [13×2] matrix **270** as shown in FIG. **8**, because there are, by example, thirteen available FDM channels **190**A–**190**M (j=1–13) and two visible satellites **12**", **12**' (k=1,2) to the user terminal **13**'.

The master controller **380** of the GOCC **38**, or in the alternative, the gateway **18**, in step **A6** of FIG. **6**, selects and assigns the appropriate FDM channel **190** to the user terminal **13**' requesting service in accordance with the procedure described below with reference to the flow chart in FIG. **9**. Thus, the procedure depicted in the flow chart of FIG. **9** is a sub-sequence included in step **A6** of FIG. **6**. In step **B1** of the flow chart in FIG. **9**, a determination is made as to whether there is a common FDM channel j_1 to each satellite **12**", **12**' (e.g. channel $(j_1,1)$ and $(j_1,2)$) such that the predicted average total interference $\mu(j_1,1)$ and $\mu(j_1,2)$ of that channel to each satellite is the minimum average total interference $\mu(j,k)$ from the channels **190**A–**190**M (j=1–13) in the return link **17***b* to the corresponding satellite **12**", **12**' (i.e. $\mu(j_1,1) \leqq \mu(1-13,1)$ and $\mu(j_1,2) \leqq \mu(1-13,2)$). If there is a channel j_1 common to both satellites (i.e. $(j_1,1)$ and $(j_1,2)$) having the minimum interference density p in comparison to the other channels to the corresponding satellite **12**", **12**', then in step **B2**, the new user terminal **13**' is assigned the channel j_1. If, however, the channel having the lowest interference density in each satellite is not the same channel (e.g. $\mu(1,1)$ is the lowest interference density in satellite **12**" but $\mu(5,2)$ is the lowest interference density in satellite **12**') then in step **B3**, a determination is made as to which FDM channel j_2 to both satellites has an average interference density $\mu(j_2,1)$ and $\mu(j_2,2)$ less than a predetermined threshold value. This threshold value may be determined from system simulations or based on operational (trend analyses) data and modified as appropriate. If such an FDM channel j_2 is found in step **B3**, then in step **B4**, the new user terminal **13**' is assigned to the FDM channel j_2.

Otherwise, if there is no channel common to both satellites having an interference density $\mu(j_2,1)$ and $\mu(j_2,2)$ less than the predetermined threshold value, then in step **B5** a determination is made whether the average interference density of the channel j_3 in one satellite, for example, $\mu(j_3,2)$ in satellite **12**' (k=2), is less than the threshold (the average interference density $\mu(j_3,1)$ of the comparable channel in the other satellite **12**" (k=1) being greater than the threshold). If Yes, then in step **B6**, a further determination is made whether the elevation angle between the user terminal **13**' and satellite **12**" (k=1), corresponding to the channel j_3 with the higher interference density $\mu(j_3,1)$, is higher than the elevation angle to satellite **12**' (k=2) having the channel j_3 with the lower interference density $\mu(j_3,2)$. If Yes, then in step **B7** and the user terminal **13**' is assigned to that FDM channel j_3. This results in the satellite **12**", at the higher elevation angle having (see FIG. **4**) to suffer greater interference. This is acceptable because visible satellite **12**' at the lower elevation angle presents a worse overall path to the signals and therefore needs to have a lower overall interference.

If the answer in step **B5** is No, (i.e. the channels to both satellites **12**", **12**' have an average interference density $\mu(j,k)$ greater than the threshold value) steps **B6** and **B7** are skipped and step **B8** is performed. As shown in FIG. **9**, step **B8** is also performed if the answer in step **B6** is No (i.e. the satellite **12**" corresponding to the channel j_3 having an interference density below the threshold value has a higher elevation than the satellite **12**' with the channel j_3 having an interference density above the threshold value). In step B**8**, a determination is made as to which channel j_4 has the minimum combined average interference density ($\mu(j_4,1)+\mu(j_4, 2)$) across both satellites **12**", **12**' (k=1–2) from the combined interference density ($\mu(1–13,1)+\mu(1–13,2)$) across both satellites for all available channels **190A–190M** (j=1–13). Then, in step B**9** of FIG. **9**, the user terminal **13**' is assigned to this FDM channel j_4. This is essentially a fall-back position which will assure that, on an average, the visible satellites **12**", **12**' will experience lower interference.

After the new user terminal **13**' is assigned a communication channel, the interference database represented by matrix **200** (see FIG. **5**) may then be updated. The database matrix **200** is updated by entering the additional interference value $\mu(j,k)$, as calculated above, for the appropriate channel $j_{1\text{-}4}$ to which the new user terminal **13**' was assigned in the satellites and beams through which the return link is established. For example, if FDM channel **190A** (i.e., j=1) is deemed the appropriate FDM channel $j_{1\text{-}4}$ to assign the user terminal **13**' (in any of steps B**2**, B**4**, B**7** or B**9** of the procedure in FIG. **9**) the total interference (I_o/N_o) value for channel **190A** (j=1) in all of the visible satellites **12**", **12**' in the database are replaced with the calculated total interference values $\mu(1,k)$ for the subject channel and satellites **12**", **12**'. When the user terminal **13**' requests a termination of services, the additional interference ($\Delta I_o/N_o$) for the subject channel **190A** and visible satellites **12**", **12**', as calculated above, may then be subtracted from the updated $\mu(1,k)$ value in the database and the new updated total interference density value stored in the database matrix **200**. As each new user terminal requests and terminates service, this process is repeated with the interference within each FDM channel **190** of each beam of each satellite (registered in the database matrix **200**) being continually updated. This database matrix **200** thus represents a continuous mapping of the overall interference to thermal noise densities within each of the satellites **12** in the constellation of satellites of the communication system **10**, and is used to optimally assign new user terminals within the set of available FDM channels **190**.

It is also within the scope of this invention to use the directional capability of fixed user terminals **16** with directional antennas to minimize the interference in a return link FDM channel **190**. The directional antennas may include antennas that are steerable and-non steerable. The steerable, or pointable, antennas may be mechanically steerable (e.g., by using a gimball) or electronically steerable. The steerable antennas may also include those capable of producing a number of fixed directional beams, and steering may be accomplished by beam selection. Referring still to FIG. **4**, included among the clusters of user terminals **13**, **13**' communicating through covisible satellites **12**", **12**' are fixed radio-telephones **16**' with directional antennas **13***b*'. Some of the fixed radio-telephones **16**' of the satellite communication system **10** may have steerable directional antennas **13***b*' so that the antenna may track a satellite **12**", **12**' along its orbital path. Other fixed radio telephones of the communication system **10** may have substantially non-steerable directional antennas (not shown). In the case of fixed radio-telephones with steerable directional antennas **13***b*', the antenna **13***b*' may be pointed at a satellite **12**", **12**' which has a minimum number of hand-held radio-telephones already allocated thereto. An overall indication as to the number of user terminals already allocated to a given satellite **12**", **12**' may be obtained from the updated database matrix **200** which identifies the total interference density per channel per satellite as previously mentioned. As also mentioned above, the information from the updated database matrix **200** may be obtained from the master controller **380** of the GOCC **38**, or in an alternative embodiment may be obtained by circuitry in the gateway **18**.

The type of the user terminals already communicating on the satellite is registered by the master controller **380** (i.e. from the data obtained in step A**2** of the channel allocation process depicted by the flow chart in FIG. **6**). Thus, when the fixed radio-telephone **16**' with a steerable directional antenna requests service from the gateway **18**, the master controller **380** of the GOCC **38** locates the position of the terminal and identifies the terminal as being a fixed radio-telephone (step A**2** of FIG. **6**). The master controller **380** then identifies the satellite **12**", **12**' with the lowest number of hand-held radio-telephones from the visible satellites and commands the fixed radio-telephone **16**' to steer its directional antenna **13***b*' so as to aim at that satellite. The communication link between the fixed radio-telephone and gateway is then established through that satellite. This further minimizes the interference in an FDM channel which is serving handheld user terminals. In the case of a fixed radio-telephone with a non-steerable antenna, the directional nature of the antenna may otherwise be utilized to allocate that user terminal to a satellite **12**", **12**' with a minimum number of hand-held user terminals. Here, at the time the fixed user terminal requests service, the master controller **380** of the GOCC **38** is otherwise aware that the terminal is a fixed radio-telephone and also of the orientation of the field of view of the non-steerable directional antenna of the terminal. The master controller **380** may then proceed to assign the fixed radio-telephone to the satellite used by a minimum of the hand-held user terminals which is within the field of view of the non-steerable directional antenna of the fixed radio-telephone.

In an alternate embodiment, use of the directional capability of fixed user terminals **16** may be accomplished by the gateway **18**. The type of user terminals already communicating on the satellite may be registered by the gateway **18** and, when the fixed radio-telephone **16**' with a steerable directional antenna request services from the gateway **18**, the gateway **18** locates the position of the terminal and identifies the terminal as being a fixed radio-telephone (step A**2** of FIG. **6**). The gateway **18** then identifies the satellite **12**", **12**' with the lowest number of hand-held radio-telephones from the visible satellites and commands the fixed radio-telephone **16**' to steer, or point, its directional antenna **13***b*' so as to aim at that satellite. The communication link between the fixed radio-telephone and gateway is then established through that satellite. At the time a fixed user terminal with a non-steerable antenna requests service, the gateway **18** is otherwise aware that the terminal is a fixed radio-telephone and also of the orientation of the field of view of the non-steerable directional antenna of the terminal. The gateway **18** may then proceed to assign the fixed radio-telephone to the satellite used by a minimum of the hand-held user terminals which is within the field of view of the non-steerable directional antenna of the fixed radio-telephone.

In both cases above, the system **10** minimizes interference in FDM channels where hand-held user terminals are assigned, because the transmit power of hand-held radio-telephones is generally more limited (due to limited battery power, desire to extend talk time). The typically high antenna gain characteristic of fixed radio-telephones as well as the ability to operate nominally at a lower energy per bit to noise density rate $E_b/(N_o+I_o)$ than mobile user terminals (because the fixed user terminals remain stationary with a clear line-of-sight to the satellites and operate in an additive white Gaussian noise propagation channel) makes the fixed radio-telephones **16** preferable to assign to FDM channels containing hand-held user terminals.

The present invention provides for a more optimal loading of the satellites **12** in the satellite communication system **10** (see FIG. **1**), with a concomitant improvement in system capacity and a reduction in user terminal transmit power needs.

While the invention has been described as utilizing the master controller **380** of the GOCC **38** or, in an alternative embodiment, as using circuitry in the gateway **18**, it should be realized that the invention is not limited to being achieved either in the master controller **380** or the gateway **18**. The invention may be implemented exclusively in the master controller **380**, or exclusively in the gateway **18**, or may be implemented in a manner that includes both the master controller **380** and the gateway **18**.

Although described in the context of a DS-CDMA communication system, it should be realized that this invention also has applicability to other satellite communication systems that utilize, by example, Time Division Multiple Access (TDMA) techniques. This invention may also be applied to other than low earth orbit (LEO) satellite communication systems, such as medium earth orbit (MEO) satellite communication systems, or geo-synchronous (GEO) satellite communication systems.

Thus, while this invention has been particularly shown and described with respect to preferred embodiments thereof, it will be understood by those skilled in the art that changes in form and detail may be made therein without departing from the scope and spirit of this invention.

What is claimed is:

1. A method for maximizing capacity of a satellite communication system comprising the steps of:

finding a total interference in each channel of a plurality of channels which subdivide a predetermined frequency band of a return link to each satellite from a plurality of satellites of the communication system;

calculating a predicted total interference from an addition of a first user terminal on each channel of the plurality channels in the return link to each of at least two satellites of the plurality of satellites;

determining if the predicted total interference in a first channel of the plurality of channels is a minimum value relative to all predicted total interference values; and

allocating the first channel to the first user terminal if the predicted total interference in the first channel is the minimum value.

2. A method as in claim **1**, wherein if the predicted total interference in the first channel is not a minimum, the method further comprises the step of determining if the predicted total interference in a second channel is less than a predetermined threshold value; and allocating the second channel to the first user terminal if the predicted total interference in the second channel is less than the threshold value.

3. A method as in claim **2**, wherein if the predicted total interference in the second channel is not less than the threshold value, the method further comprises the steps of:

determining if the predicted total interference in a third channel is less than the threshold value;

if yes, then determining if the first satellite is at an elevation angle, relative to the user terminal, that is smaller than an elevation angle of a second one of the two satellites; and

if yes, allocating the third channel to the first user terminal.

4. A method as in claim **3**, wherein if the predicted total interference in the third channel is not less than the predetermined threshold, or if the elevation angle of the first satellite is not smaller than the elevation angle of the second satellite, the method further comprises the step of allocating the user terminal a fourth channel, wherein the fourth channel exhibits a minimum combined average interference density across said first and second satellites, from the combined interference density across said first and second satellites for all available channels.

5. A method as in claim **1**, wherein the step of finding the total interference comprises the steps of:

calculating an interference in each channel of the plurality of channels of the return link to each satellite at a predetermined initial time; and

updating the interference in each channel of the plurality of channels of the return link to each satellite by adding the interference of each user terminal allocated to a corresponding one of the channels and subtracting the interference of each user terminal which terminates service on the corresponding channel.

6. A method as in claim **5**, wherein the interference in each channel of the plurality of channels of the return link to each satellite is updated at predetermined time periods after the initial time.

7. A method as in claim **1**, further comprising the step of registering the total interference in each channel of the plurality of channels of the return link to each satellite in a database of the satellite communication system.

8. A method as in claim **1**, wherein the step of calculating a predicted total interference comprises the step of identifying a location and type of the first user terminal when the user terminal request service.

9. A method as in claim **1**, wherein a processor of the satellite communication system registers other radio frequency services located proximate to the first user terminal.

10. A method as in claim **1**, wherein the predicted total interference is calculated when the first user terminal requests service.

11. A method for assigning a frequency channel to a user terminal of a satellite communication system, the user terminal being illuminated by at least two satellites from a plurality of satellites of the communication system, wherein the method comprises the steps of:

identifying at least one of a location and a type of the user terminal when the user terminal requests service;

determining if a first frequency channel from a plurality of frequency channels for a return link of the user terminal to each one of the two satellites has a minimum total interference density relative to the plurality of frequency channels;

if yes, assigning the first frequency channel to the user terminal;

if no, then determining if a second frequency channel from the plurality of frequency channels for the return link of the user terminal to each satellite has a total interference density below a predetermined threshold;

if yes, assigning the second frequency channel to the user terminal;

if no, then determining if a third frequency channel from the plurality of frequency channels has a total interference density below the predetermined threshold for the return link of the user terminal to a first one of the two satellites and a total interference density above the predetermined threshold for the return link of the user terminal to a second one of the two satellites;

if yes, then determining if the first satellite is at a lower elevation with respect to the user terminal than the second satellite;

if yes, then assigning the third channel to the user terminal; and

if no, or if the total interference density in the third frequency channel for the return link of the user terminal to the first satellite is above the predetermined threshold, then assigning a fourth frequency channel from the plurality of frequency channels for the return link of the user terminal; wherein

the fourth frequency channel exhibits a minimum combined average interference density across said first and second satellites, relative to the combined interference density across said first and second satellites for all available channels.

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